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THE ANALYTIC HIERARCHY PROCESS: AN EFFECTIVE TOOL FOR A STRATEGIC DECISION OF A MULTIDISCIPLINARY RESEARCH CENTRE

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The external orientation of academic research centres has a high impact on their internal organization. A multidisciplinary research centre of the University of Groningen in the Netherlands is concerned with a strategic, organizational decision impelled by a shift in its external orientation. This decision implies a choice for either an organizational structure based on disciplines or an organizational structure based on the fields of application of research. Due to diverging opinions concerning the desirability of each alternative, a multi-criteria decision-making approach has been applied. Saaty's analytic hierarchy process (AHP) has been used to facilitate joint decision-making processes by evoking consistent logical foundations and consensus formations. Strategic management has used a forward AHP model to determine the future research activities of this centre based on its external orientation. Subsequently, two comparable decision-making groups have used a backward AHP model to choose the most appropriate organizational structure, based on criteria for scientific research. Feedback procedures have reduced disagreements and have led to a clear decision for a structure based on the application fields of research.

4.1 Introduction

University research results carried over to start a company or become a product in an existing company is the most successful model for the development and transfer of technology (Bell, 1992). However, the impact of close university-industry co-operation is likely to interfere with the academic freedom of universities. Academic freedom incorporates the freedom to pursue disinterested, long-term basic research (Lee, 1996). In contrast to this type of research, industry often contracts basic or applied research that contributes to the evolution of their core competences (Bloedon and Stokes, 1994). Moreover, to entrust these critical parts of its research to outsiders, industry must have confidence that results will be produced in a limited time period (Van Rossum and Omta, 1999). In addition to these restrictions on academic freedom, research spending by universities is also limited through the desire of industry to achieve and verify an adequate return on investment from the collaborative research (Rhea, 1997). Nevertheless, these impacts of close collaboration are to an increasing extent being accepted by universities due to declining governmental R&D support. Industry's effort to outsource research provides universities with some financial relief (Lee, 1996). Furthermore, industrial firms, in some sectors at least, are increasingly dependent upon "strategic" fundamental research. Universities increasingly conduct such research.

Universities collaborating with industry need to make challenging decisions to adapt to these rapidly changing circumstances. To reduce costs and maximise the use of available resources, many universities have undergone considerable reorganizations. Scientists from different disciplines are brought together in an environment that induces an effective and efficient use of resources. In this setting, ideas can flourish and speculative lines of investigation can be pursued alongside those of a more obvious and immediate value (Davies, 1996). Other effective adaptations imply an intensification of links between basic and applied research and an improvement of mechanisms for the commercialisation of basic research results to industry (Geisler, 1995). In this respect, the research goals of university research units are increasingly ambivalent: they have to contribute to both internal and external science goals.

In this article, a description is given of the Division of Artificial Organs (AO), part of the Medical Faculty of the Dutch University of Groningen. To an increasing extent, this multidisciplinary research centre favours close collaboration with industry. Currently, this

centre is considering adapting itself to its environment. Therefore, its spatial organizational structure is being reconsidered. The alternatives are a structure based on academic disciplines and a multidisciplinary structure based on the fields of application of research. Employees have a diverging range of opinions regarding the appropriateness of these alternatives.

The aim of this study is to assist in this strategic organizational decision by using Saaty's analytic hierarchy process (AHP) in order to evoke logical foundations based on a consensus or an acceptable compromise. Two comparable multi-disciplinary decision groups composed of employees originating from the same disciplines and organizational backgrounds have used AHP to reach a joint decision. With this composition, each team represents the diverging range of opinions at AO regarding this decision. Both decision groups considerably reduced disagreements and independently made a clear choice for a multidisciplinary structure based on the fields of application of research results. Its corresponding results led to an approval of the consequences of this decision by the decision-makers.

4.2 Organizational orientations of academic research units

The environment of academic research centres consists of sources of demand, resources, constraints, and research problems that influence the development of scientific knowledge (Groenewegen, 1988). Scientists are dependent on their external relations providing these sources (Mulder and Vergragt, 1989). However, these external sources are ambiguous; they are uncertain, and may conflict or shift over time (Zeldenrust, 1989). Therefore, renegotiations of the external relations are required when environmental changes affect the importances of the different sources. An important change is the current decline in governmental R&D support. A marginal shift in the funding structure of academic research centres may cause a significant organizational reorientation (Lee, 1996). Academic research units adapt the internal structure and processes to the renewed requirements of their external relations (Zeldenrust, 1989).

In general, there are two types of organizational orientation of academic research units. The first, and most traditional orientation is to focus principally on the focal university. Academic research units following this strategy are mainly focused on basic research. The researchers often have a mental model of "intellectual hierarchy" that views user-oriented

applied research as second class (Armstrong, 1991). They produce a considerable amount of scientific knowledge for consumption and use by employers, technologists, and the educated public. However, the most highly valued knowledge is produced for the consumption and use of colleagues in the process of producing novelty and innovations themselves (Whitley, 1984). These academic research units are confronted with systems of evaluation and concomitant reward structures based on traditional "public science" criteria like quantity and quality of publications and international prestige. The familiar discipline-based, internally driven, individually run structures currently dominate these research units (Tijssen and Korevaar, 1997).

Since applied science and science-based technology is of vital importance in the major knowledge-based industries (Tijssen and Korevaar, 1997), some academic researchers should reorient their academic philosophy. The emphasis on basic research should shift to an emphasis that seeks a better balance between basic and user-oriented applied research (Geisler, 1993). A second organizational orientation of academic research units incorporates this conception. While remaining part of the focal university, the importance of collaboration with industry is recognised.

Corresponding to this new emphasis, many university research labs have now entered both short- and long-term research collaborations with industry (Dasgupta and David, 1994). The resulting behaviour of the researchers involved is evidently different from researchers pursuing traditional university-bound research. The former tend to be more interdisciplinary in orientation, more actively involved in university-industry research collaboration, and more supportive of extension oriented educational programme research (Rahm, 1995). The academic research units with this mixed focus constitute practically oriented, interdisciplinary, network-dominated, flexible structures (Tijssen and Korevaar, 1997). However, the evaluation systems and reward structures of the focal universities -and therefore of the academic research centres- are generally unilaterally based on the traditional academic criteria. In contrast, industry rewards academic research centres on the basis of their ability to produce customer utilities.

Research units within one university vary in their emphasis on either basic or user-oriented applied research. Moreover, their external sources generally vary. These discrepancies are obstacles to a uniform organizational structure throughout the university. Thus, each research unit should make its own decision for an organizational structure while taking into account the nature of its research goals.

To analyse the decision for a structure in all its diversity, different points of view should be integrated. Haselhoff (1977) gives a schematisation of different points of view regarding organizations. Organizations can be perceived as open systems in their environment. This view implies that a sensible ratio of basic to applied research can be derived based on each research unit's interest in external actors and their sources of demand, resources, constraints and research problems. This ratio of basic to applied research represents the feasible degree to which research units desire to emphasise either basic or applied research.

We claim that this ratio is at the root of the decision regarding the organizational structure. Different criteria are relevant for this subsequent choice. These criteria can be derived from the two remaining points of view. Haselhoff's second point of view is to perceive organizations as technical-economical systems. Based on this view, criteria concerning the effectiveness and efficiency of research projects are considered. Scientific depth reflects effectiveness from the standpoint of disciplinary-based science. The application value of research reflects effectiveness from the standpoint of user-oriented interdisciplinary science. It incorporates the internal and external application value of the research results. With respect to efficiency, lead-time is relevant. It is a frequently used measure of the process performance of R&D projects. Haselhoff's final point of view is the perception of organizations as social systems. Based on this view, the motivation of the employees for working in their research unit is assessed.

Our primary hypothesis is that a sound decision for an organizational structure of an academic research unit can be based on the comparison of these different criteria related to scientific depth, application value of results, lead-time and motivation. These criteria assess the research activities corresponding to the realistic but desired ratio of basic to applied research.

4.3 The analytic hierarchy process (AHP)

The strategic organizational decision problems universities face have multiple criteria with respect to diverging qualitative domains. These organizational decisions are technically and politically complex and require frequent group decision-making meetings (Saaty, 1989). Interest in group decision-making continues to grow. In our view, AHP is a multi-criteria

decision-making technique well suited to derive collective judgements in this context in that it facilitates the quantitative comparison of alternatives. As opposed to more traditional evaluation techniques, it can account for not only quantitative but also for qualitative impacts. Other reasons to discard alternative multidimensional evaluation techniques in this context is the irrelevance of the probability of occurrence of impacts (e.g., multiple attribute utility theory [MAUT]), and such practical difficulties as a necessarily large data set (e.g., correspondence analysis).

AHP was developed for analysing a variety of decisions concerning complex technological, economical and socio-political problems. It has been applied successfully in decisions about, for example, product/process/project selection (Tang and Nam, 1993; Karbhari, 1994; Barbarosoglu and Pinhas, 1995; Partovi, 1994; Davis and Williams, 1994), resource allocation (Liberatore *et al*, 1992; Ossadnik, 1996; Partovi and Hopton, 1994) performance measurement (Lee *et al*, 1995; Madu, 1994) and even a political problem (Carlsson and Walden, 1995). Despite these empirical successes, AHP is not immune to controversy; as is evidenced by the existence of several alternative procedures besides the conventional procedures of AHP described in this article.

The first step in the AHP is to structure a complex decision into a hierarchy of factors. The basic structure of AHP consists of three hierarchical levels: objectives, criteria, and alternatives. By breaking the problem into these subunits, the decision-maker can focus on smaller sets of decisions. One of the most extended elaborated structures consists of a forward and backward part. The forward planning process is the resultant scenario or state of a system determined by the existing state and the actors who pursue their objectives, policies, and individual outcomes. The desired outcome is brought about by applying policies to influence actors to remove obstacles in the way of this outcome. This is the backward planning process.

Pairwise comparisons of the different factors, based on a nine-points ordinal scale, indicate the relative importances of or the relative preferences for the factors. People already intuitively use these pairwise comparisons to reduce complexity. In order to derive valid results, all factors must fall within the same order of magnitude (Saaty, 1994). A major strength of the AHP is that it allows for -and explicitly deals with- inconsistencies. It provides a measure of the ratio of inconsistency (CR) that indicates the degree to which each pairwise comparison is consistent with the remainder of the comparisons. Saaty indicates a maximum value for this measure. Weighting factors and priorities for these factors are estimated

according to a mathematical approach proposed by Saaty. See appendix A for a more elaborated overview of the quantitative methodology of the AHP.

Alternative procedures have been developed with respect to the measurement scale (Lai, 1995; MacKay *et al*, 1996), consistency index (Monsuur, 1996), prioritisation techniques (Dodd and Donegan, 1995; Hauser and Tadikamalla, 1996; Bryson and Mobolurin, 1994; 1997; Bryson, 1995; Despotis, 1996; Schoner *et al*, 1993), group aggregation techniques (e.g. Ramanathan and Ganesh, 1994; Van Den Honert and Lootsma, 1996), and additional approaches (Rosenbloom, 1996; Ramanathan and Ganesh, 1995; Genest and Zhang, 1996). However, when a group decision support tool is to improve judgements and intuition by providing a surveyable and comprehensible support, the conventional AHP, provided by the software package "Expert Choice", is a suitable approach. This user-friendly approach enhances effectiveness due to explicit logical foundations, efficiency by dividing the decision problem in subunits and reliability by providing a consistency index. Comprehensible graphics regarding weighting factors and preferences improve the general overview during the decision process. Furthermore, this approach leaves ample room for consensus building.

The basic version of AHP has been developed to support decision-making by an individual decision-maker. Additional software allows a decision group to use this approach. Each decision-maker inserts his pairwise comparisons and this software computes collective judgements. However, in this study we shall adapt the procedures corresponding to the basic version of AHP. By adding feedback links between the decision- makers, the decision-makers are induced to give collective judgements based on a compromise or even consensus.

4.4 Case study

4.4.1 The Division of Artificial Organs (AO)

In this study, AHP is applied in a case study performed in an academic research centre. This multidisciplinary research centre is the Division of Artificial Organs (AO), part of the Faculty of Medical Sciences of the University of Groningen in the Netherlands. The main goals of Artificial Organs are:

- Enlarging scientific knowledge on Biomedical Technology in general and on artificial organs in particular;
- Spreading scientific knowledge and results from scientific research in society;
- Educating medical and technical students in Biomedical Technology.

To fulfil these goals, AO is concerned with both basic and applied research. Basic research is directed toward biocompatibility and non-invasive measurement methods. This research is mainly oriented towards Physics. Applied research is particularly focused on three fields of application, which are: “Heart and Circulation”, “Orthopaedics and Revalidation” and “Soft Tissue Replacement”. A differentiated type of applied research is commercial contract research for third parties. The relevant subjects of research here are strongly related to the other subjects of research. Contract research encompasses short-term projects, in contrast with other projects of AO, which often last many years. Four internal laboratories are available to support all research projects; a laboratory for medical product development, a laboratory for biocompatibility, a laboratory for physiological instrumentation, and a lab for voice research. The scientific results of the research projects are mainly published in scientific publications and presented at international congresses.

In addition to the research activities, Artificial Organs provides a small part of the education given at the Faculty of Medical Sciences of the University and Polytechnics. For both institutes, two examination subjects are provided. Moreover, several apprenticeships are available at Artificial Organs for its medical and technical students.

AO’s twenty employees -who are mainly mechanical engineers, physicists and physicians- perform these activities. They work in an organizational structure based on research projects. However, this project-based structure gives no structural support for AO’s strategic choices. It has been the occasion of some incongruent and ambiguous choices. Since basic research and applied research are subsumed in separate research projects, the emphasis towards either basic or applied research can shift by initiating new projects. Moreover, this project-based structure is no foundation for either a discipline-based setting or a multidisciplinary setting. This has resulted in a mixed discipline- and multidiscipline-based setting. The project members of the research projects originate from the same discipline, except for some multidisciplinary applied projects. The project members of basic research projects are all physicists. They, in particular, tend to be isolated from the rest of the employees working in applied research projects. In this way, the physicists form an incongruous entity within the Faculty of Medical Sciences.

4.4.2 Decision problem

Because AO desires to contribute particularly to “real-life” problem solving, its research is increasingly being directed to medical problems originating in the university hospital. As a result of this focus, AO embarks on research topics that are also interesting for industry. Despite its diverging interests, the Faculty of Medical Sciences has allowed AO to perform a relative highly amount of applied research. In addition, AO hopes to strengthen its ties with industry by making its research results more easily accessible to industry. Currently, the final product of its research is generally a tailor-made prototype instead of a reproducible production model. To overcome this commercialisation gap, an innovation workshop has recently been initiated, in which prototypes of scientific research can be augmented to small production series. The centre closely co-operates with Polytechnics in order to effectuate this initiative.

To adapt to its ambiguous environment, AO is reconsidering its spatial organizational structure. The transfer of the entire department to another location in the near future seems to be a suitable opportunity to reorganise. The future structure has to fulfil the demands imposed by its external relationships as effectively as possible. Alternatives are an organizational structure based on academic disciplines and a multidisciplinary structure based on the fields of application of research. In this second option, the conspicuous distinction between the members involved in basic and those involved in applied research will be discontinued. The fields of application of AO will integrate basic and applied research projects. Due to diverging interests, different opinions exist with respect to the desirability of each alternative. Therefore, explicit attention should be paid to resolving disagreements while making this decision.

4.5 Research methodology

This study has been initiated to support AO in its contentious strategic decision for an organizational structure based on academic disciplines, or one based on the fields of application of research. Saaty’s AHP, provided by the software package “Expert Choice”, has been used to formulate and analyse this decision. Its support is aimed at the formation of consistent logical foundations. Moreover, its support is aimed at reducing the prevailing disagreements at AO with regard to this decision. By adding feedback links between decision

makers, the decision makers are induced to give collective judgements based on an acceptable compromise or even consensus. Those compromises are acceptable that result in a decision whose consequences are approved of by the decision makers involved.

A pilot study was conducted to assess the appropriateness of AHP in this multidisciplinary context. AHP is considered appropriate when it evokes consistent collective judgements based on an acceptable compromise or consensus. In this context, attention is paid to the additional value of using a questionnaire before group decision processes. The AHP has been used to formulate a simple decision structure for analysing the strategic decision for an organizational structure. Individual judgements of the second decision group had been collected by means of questionnaires prior to group decision processes occurring. Based on the consistencies and degrees of consensus formation of both groups, individual judgements were either asked or not asked prior to all subsequent group decision processes.

Subsequently, an extended AHP structure with a forward and backward structure was developed. In the forward AHP structure, explicit attention is paid to the desired but realistic future ratio of basic to applied research at AO. This decision structure is based on our view that a sensible ratio of basic to applied research can be derived based on each research unit's interest in external actors and their sources of demand, resources, constraints and research problems. Two strategic managers of AO have used this structure in order to give their relative preference for basic and applied research. A desired but realistic ratio of basic to applied research can be deduced from this preference.

The backward structure is based on our hypothesis that a sound decision for an organizational structure of an academic research unit can be based on the comparison of different criteria related to scientific depth, application value of results, lead-time and motivation. These criteria assess the research activities corresponding to the realistic but desired ratio between basic and applied research. According to this backward AHP structure two multi-disciplinary decision groups, each composed of four employees of AO, discussed their preferences for an organizational structure. These groups are comparable with respect to their disciplines and organizational backgrounds. Diverging judgements representing diverse experience are represented. Moreover, this constitution is an adequate representation of the actual core of AO's researchers (i.e., those who will be confronted with the consequences of the decision). Tables 1 and 2 describe the two decision groups with respect to disciplines and organizational background.

Table 1. First decision group

DISCIPLINE	INTERNAL WORK EXPERIENCE (IN YEARS)	CURRENT PROJECT
Physicist	5	Measuring devices
Physician	3	Left ventricular assist device
Mechanical engineer	3	Artificial larynx
Mechanical engineer	1	Orthopaedic implant

Table 2. Second decision group

DISCIPLINE	INTERNAL WORK EXPERIENCE (IN YEARS)	CURRENT PROJECT
Physicist	4	Measuring devices
Physician	8	Muscle fatigue
Mechanical engineer	3	Artificial larynx
Mechanical engineer	2	Left ventricular assist device

4.6 Development forward and backward AHP structure

In the AHP structure, explicit attention is paid to a strategic decision for a desired but realistic ratio of basic to applied research at AO. This strategic decision, based on AHP's forward planning process, is at the root of the decision for an organizational structure of AO. The decision for a particular organizational structure, based on AHP's backward planning process, is founded on the comparison of different criteria for scientific research. The weights of these criteria depend on the specific ratio of basic to applied research.

4.6.1 Forward part AHP structure

The AHP structure in figure 1 outlines the described situation at AO. In this first part, an AHP structure has been constructed to estimate a desired but realistic ratio of basic to applied research of AO. This estimation is grounded upon the importances of the external actors for AO. AO's future type of research will be tailored to the influences of their sources of demands, resources, constraints and research problems.

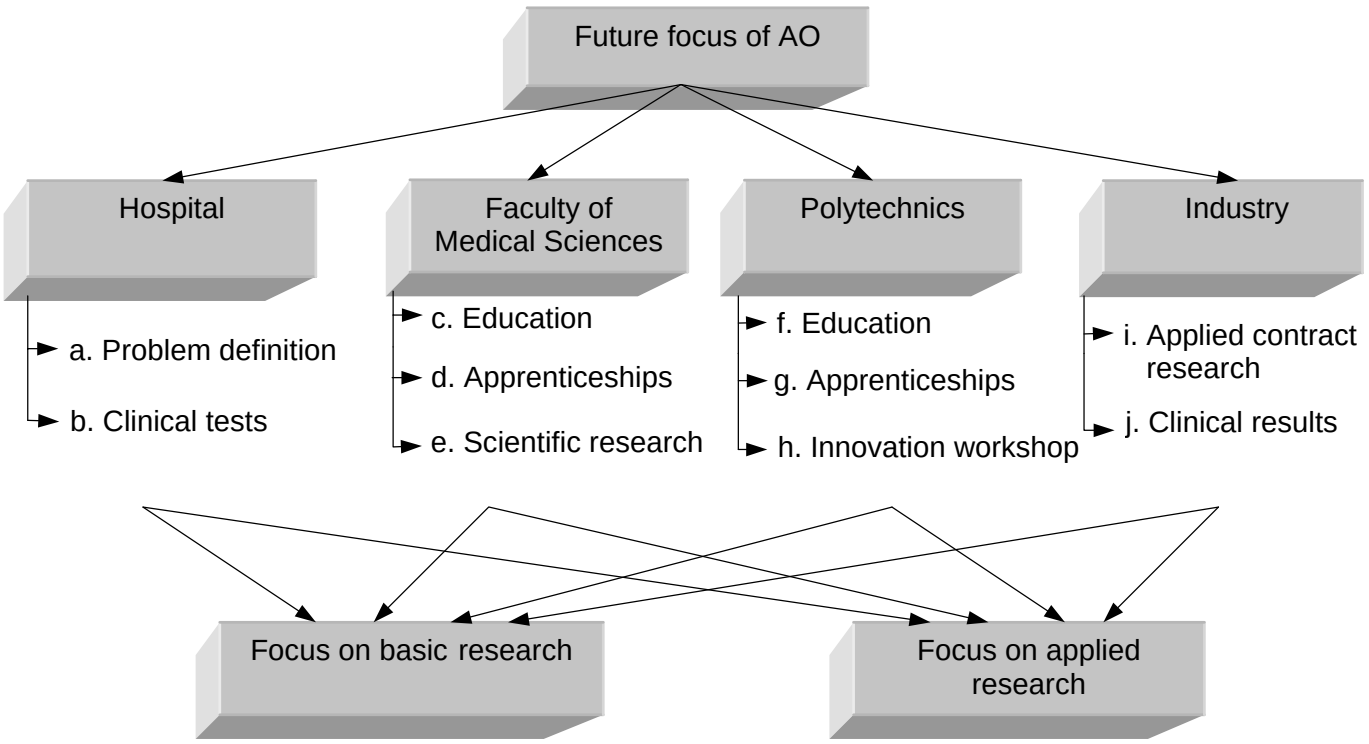


Figure 1. A hierarchy of influences on the future focus of AO

4.6.2 Backward AHP structure

An appropriate organizational structure reflects the professional level and needs of those involved (Thamhain and Wilemon, 1987). Structures determine the physical proximity of people and resources. Therefore, drivers of lead-time, scientific depth, application value of research and motivation that are related to interactions, and the utilisation of resources are integrated in the backward AHP structure.

Lead-time is used as an overall measurement of the efficiency of the research projects. Three drivers of the lead-time are formulated. The first one comprehends an efficient use of resources. With respect to interactions, two important aspects within new product development are formulated. One factor is the joint direction of personnel (Thamhain and Wilemon, 1987). Another factor related to interaction is inventiveness. Much of people's inventive activity requires input from others. Communication enhances invention in reconciling this input (Shane, 1992).

Furthermore, two different criteria related to the effectiveness of the development of knowledge are incorporated. Scientific depth reflects effectiveness based on the standpoint of disciplinary-based science. The accompanying professional growth is recognised as an important element of engineering teams (Thamhain and Wilemon, 1987). Professional growth can be stimulated by the utilisation of resources as well as interactions. The application value of research reflects effectiveness based on the standpoint of user-oriented interdisciplinary science. Complementary aspects to scientific depth, related to a user-orientation, are an internal problem orientation and a "real-life" problem orientation. This distinction is made to reflect the difference between internal and external problems. Furthermore, the essential integration of internal interdisciplinary-based competences is incorporated in the backward AHP structure.

The last criterion assesses the motivation of AO's employees. This criterion is important in R&D projects because the chances of success of a project are substantially diminished unless the motivation of everyone working on the project is high (Howell and Dipboye, 1986). Aspects with motivational value have task-oriented and socio-emotional oriented parts (Forsyth, 1990). This distinction appears in the two drivers of overall motivation: satisfying interpersonal relations and motivation for task execution.

The AHP structure in figure 2 outlines the described criteria for scientific research and their corresponding drivers. Based on these factors, a decision will be made with regard to the organizational structure of AO, given its desired but realistic ratio of basic to applied research.

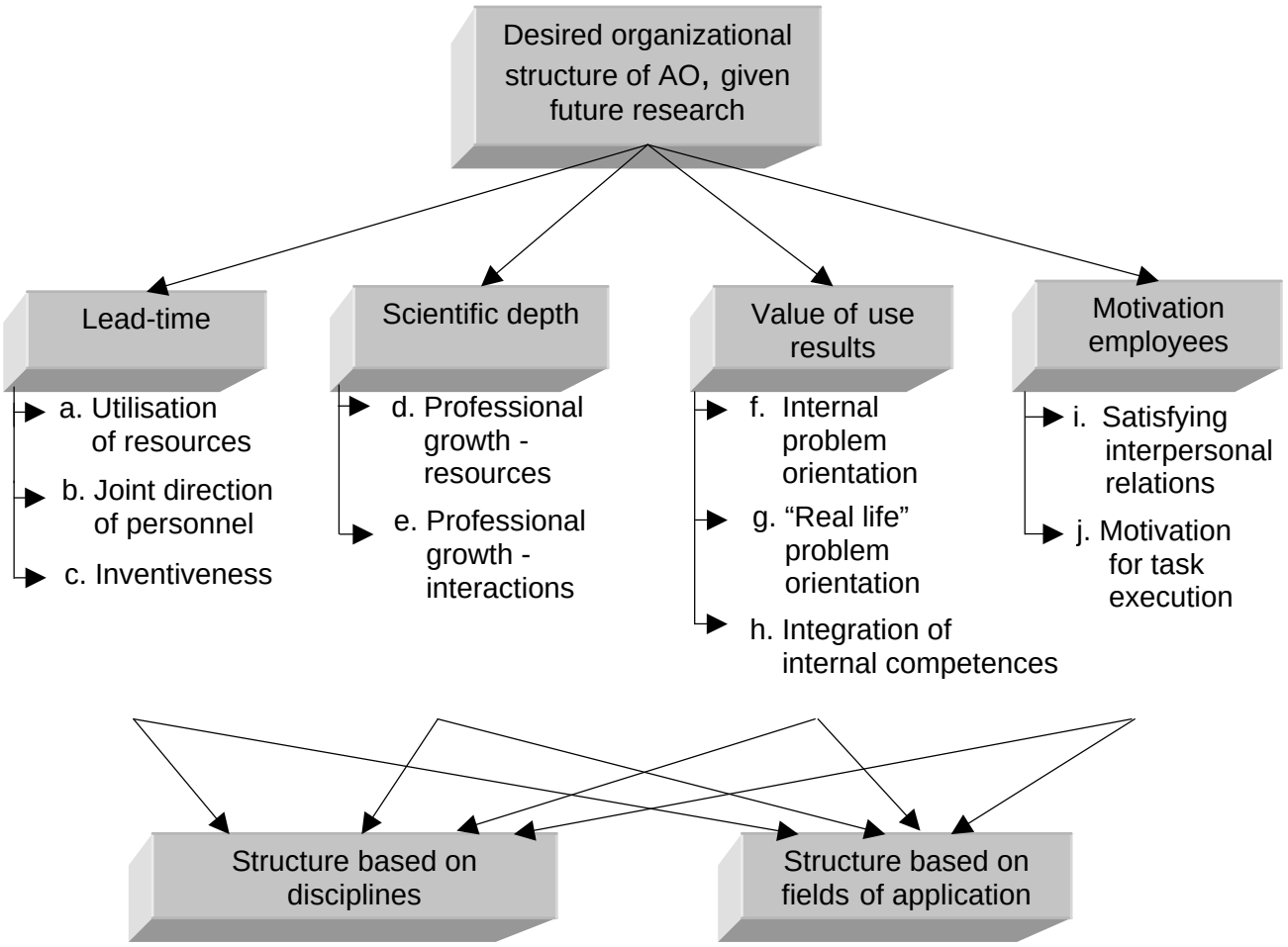


Figure 2. A hierarchy of criteria for the organizational structure of AO

4.7 Results forward and backward AHP structures

The overall results of the pilot session, in which a simple AHP structure has been used, indicate that a questionnaire contributes to the effectiveness of the decision processes. It focuses the discussion to resolve the main disagreements. This resulted, for the second decision group, in collective judgements based on a consensus. Moreover, it reduces the inconsistency of the judgements during the decision process. AHP is considered appropriate

when it evokes consistent collective judgements based on an acceptable compromise or even consensus. Correspondingly, the results of this pilot study indicate that particularly AHP procedures based on questionnaires and group decision processes are suitable. Therefore, questionnaires were used prior to all subsequent decision processes. The figures corresponding to these results of this pilot session can be found in appendix 4.1.

4.7.1 Results of the forward part of the AHP structure

Two managers of AO have discussed the forward AHP structure. Individual preferences were known prior to the joint decision process. Before the collective decision process, the individual judgements highly differed. Nevertheless, after discussions, all collective judgements were based on a consensus. Two adaptations were necessary due to inconsistent judgements. The resulting overall inconsistency ratio is 0.08, which is 80 per cent of the maximal inconsistency ratio. This inconsistency appears to be primarily caused by the ambiguous role of the focal university. The main results of this process are represented in figure 3a. The importances of the external actors are represented in the full length of the bars. Each full length is divided into two parts of which the lengths reflect the relative preferences for the two types of research. Figure 3b gives the overall preferences for the two types of research.

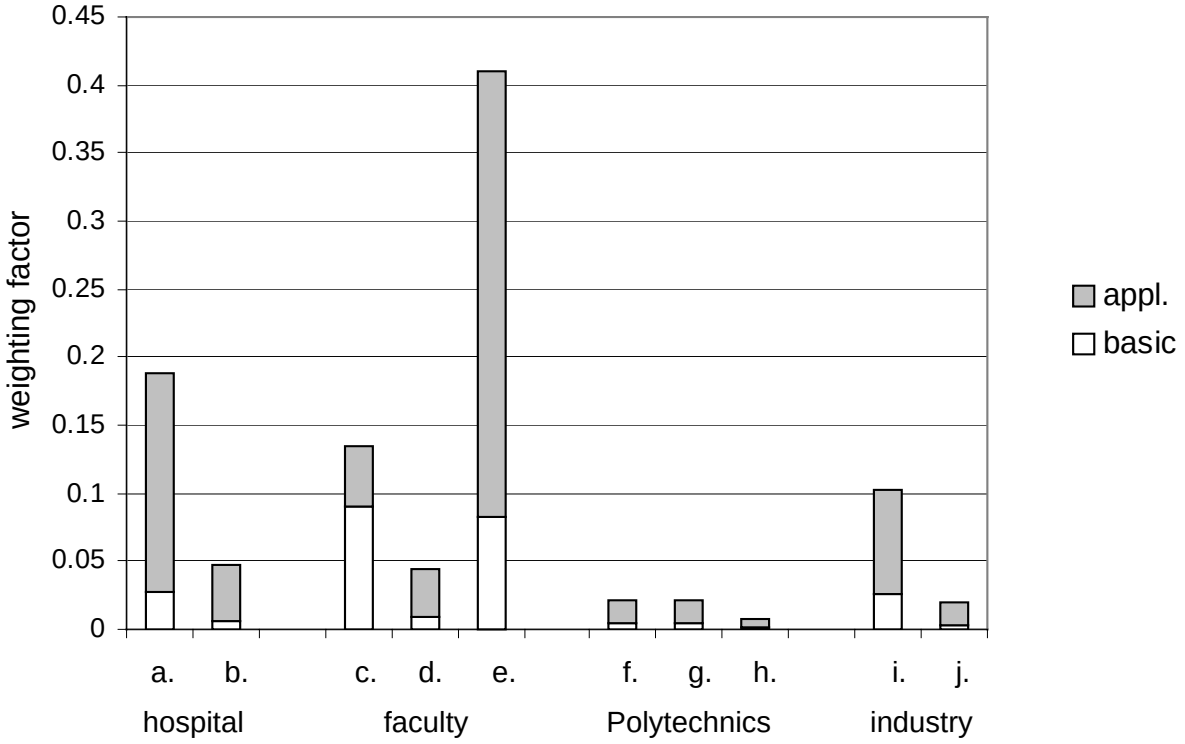


Figure 3a. Importances of the activities of the external actors

Notes: a. = problem definition; b. = clinical tests; c. = education; d. = apprenticeships; e. = scientific research; f. = education; g. = apprenticeships; h. = innovation workplace; i. = contract research; j. = clinical results; basic = basic research; appl. = applied research.

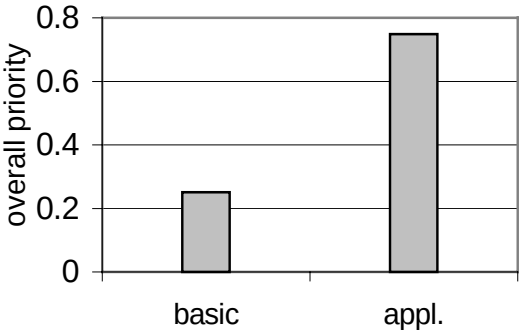


Figure 3b. Preferences for the alternatives

These results indicate that AO principally takes into consideration its relation with the Faculty of Medical Sciences, the origin of its existence. It is noteworthy that AO is not impelled by this faculty to emphasise basic research. AO has secured a pseudo-independence of the faculty, which is reflected in its focus on user-oriented applied research. The faculty has, for the most part, accepted both this focus and that the resulting interdisciplinary research activities are performed by mainly non-physicians.

Nevertheless, this focus remains a potential source of conflict, since the actual desire of the Faculty of Medical Sciences is for AO to focus on basic research related to medical sciences. If AO were to accept this request, while taking into account the sources of the other external actors, the amount of basic research activities would equal the amount of applied research activities.

Within the research activities granted by the faculty, AO is primarily oriented toward the university hospital. AO desires to define research problems based on medical problems indicated by this hospital. To a minor extent, the research activities of AO are concentrated on contract research for industry. Collaboration occurs when industries research subjects are affiliated to the established competence of AO. AO's limited interest in providing clinical results for industry indicates that the sources of industry are only an accessory matter with respect to the determination of the research activities of AO. Therefore AO is affected but not directed by the demands for effectiveness and efficiency defined by industry.

The importance of the relation with Polytechnics is negligible in comparison with the importance of the relation with the Faculty of Medical Sciences. Their importances do not fall within one order of magnitude. The reliability of the computed importance of Polytechnics is therefore questionable. However, this is only of minor meaning since its influence on the research activities of AO is in tune with the influence of the hospital and industry.

The whole picture of the influences of external actors on the research activities of AO results in an emphasis on user-oriented applied research. Of all research activities, 75 per cent will be aimed at applied research and 25 per cent at basic research.

4.7.2 Results of the backward part of the AHP structure

First decision group

The first decision group has discussed the extended backward part of the AHP structure. Multiple differences in opinion caused a proportional division of attention over all judgements with regard to the pairwise comparisons. Despite the application of a questionnaire, this decision group has given group means in order to overcome the minor differences in opinion. Nevertheless, the consistency of its collective judgements improved in comparison with the judgements derived from the application of the first AHP structure. One minor revision of one judgement of the sum of twenty-four judgements was required, taking the theoretical maximal inconsistency ratio of 0.10 into consideration. This resulted in an overall inconsistency ratio of 0.03. The collective judgements with respect to the importances of the criteria and the corresponding preferences for the alternatives are given in figures 4a and 4b.

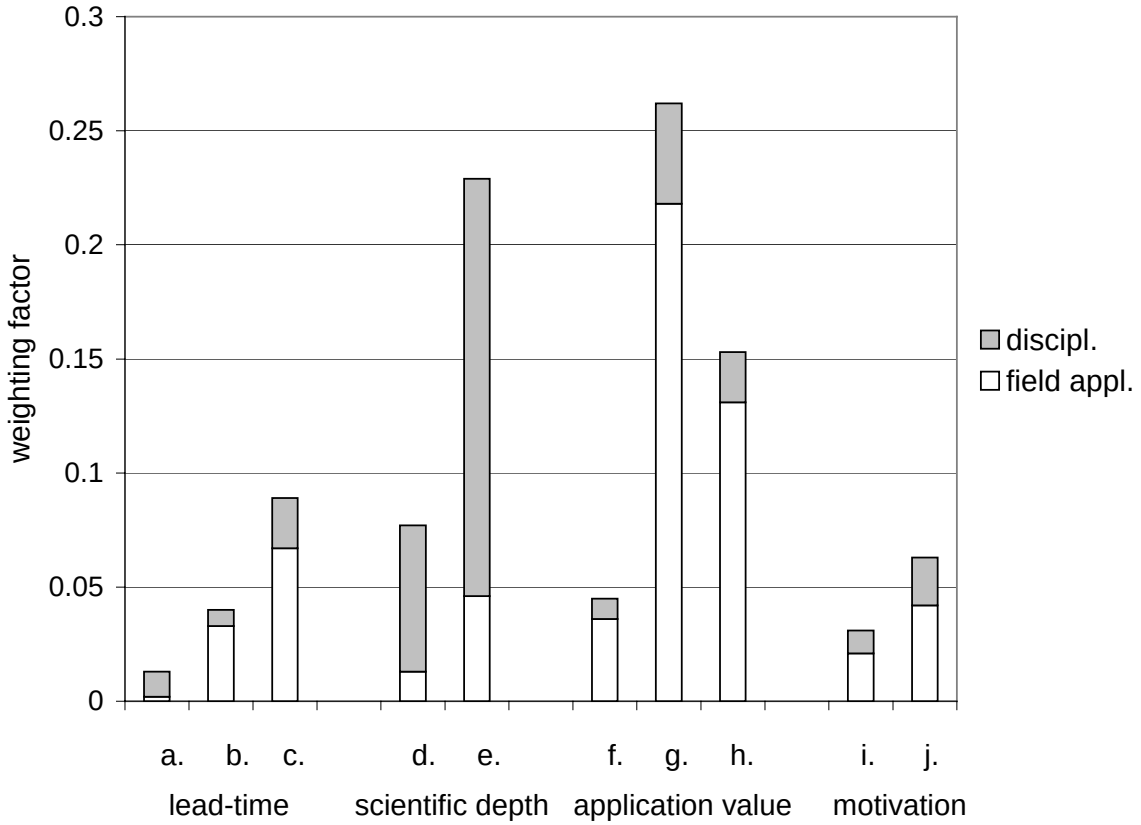


Figure 4a. Importances of the influences; first decision group

Notes: a. = efficient utilisation resources; b. = joint directions; c. = inventiveness; d. = professional growth by utilisation resources; e. = professional growth by interactions; f. = internal problem orientation; g. = external problem orientation; h. = integration internal competences; i. = satisfying interpersonal relations; j. = motivation task execution; discipl. = structure based on disciplines; field appl. = structure based on fields of application.

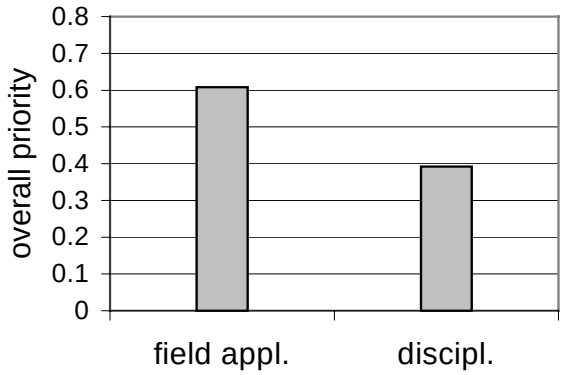


Figure 4b. Preferences for the alternatives; first decision group

The awarded weights to criteria employed in this application and in the pilot session are reasonably in accordance. Once again the first decision group accentuates the importance of effectiveness. They consider an orientation to external problems to be of utmost importance. This coincides with user-oriented applied research stressed by internal management. Furthermore, the importance of lead-time is emphasised to a minor extent. This might be explained by the fact that AO is affected but not directed by collaboration with industry. Finally, the importance of motivation with respect to the decision for an organizational structure is rated low. This decision group expects that a minimal threshold value for motivation will be achieved regardless of which organizational structures would have been applied.

Both influences on scientific depth provoke a preference for an organizational structure based on disciplines. Conversely, all influences on the application value of research ask for a structure based on the fields of application. These preferences all coincide with the observed trend of academic research units. Units oriented at universities, in which scientific depth is emphasised and rewarded, generally constitute a discipline-based organizational structure. Those units emphasising user-oriented applied research, aimed at the application value, adapt by constituting an interdisciplinary-based structure.

Apart from the influences on scientific depth, only the influence of utilisation of resources on the lead-time is related to a structure based on disciplines. However, the importance of the influences related to interactions is rated higher than those related to the utilisation of resources. Therefore, with respect to lead-time, a structure based on the fields of application is preferred. This preference is strengthened by the emphasis on the application value of research. Moreover, the overall preference agrees with the preferences according to the motivational aspects. The overall preference for a structure based on the fields of application is reflected in the weighting factors of the alternatives that are: 0.61 corresponding to a structure based on the fields of application and 0.39 corresponding to a structure based on disciplines.

Second decision group

Subsequently, the second decision group discussed the extended backward AHP structure. The initial preferences harmonized reasonably. This decision group gave collective judgements based on an actual consensus. No revisions of judgements were required due to

inconsistency. The overall inconsistency ratio is 0.05. Figures 5a and 5b give the main results based on the collective judgements.

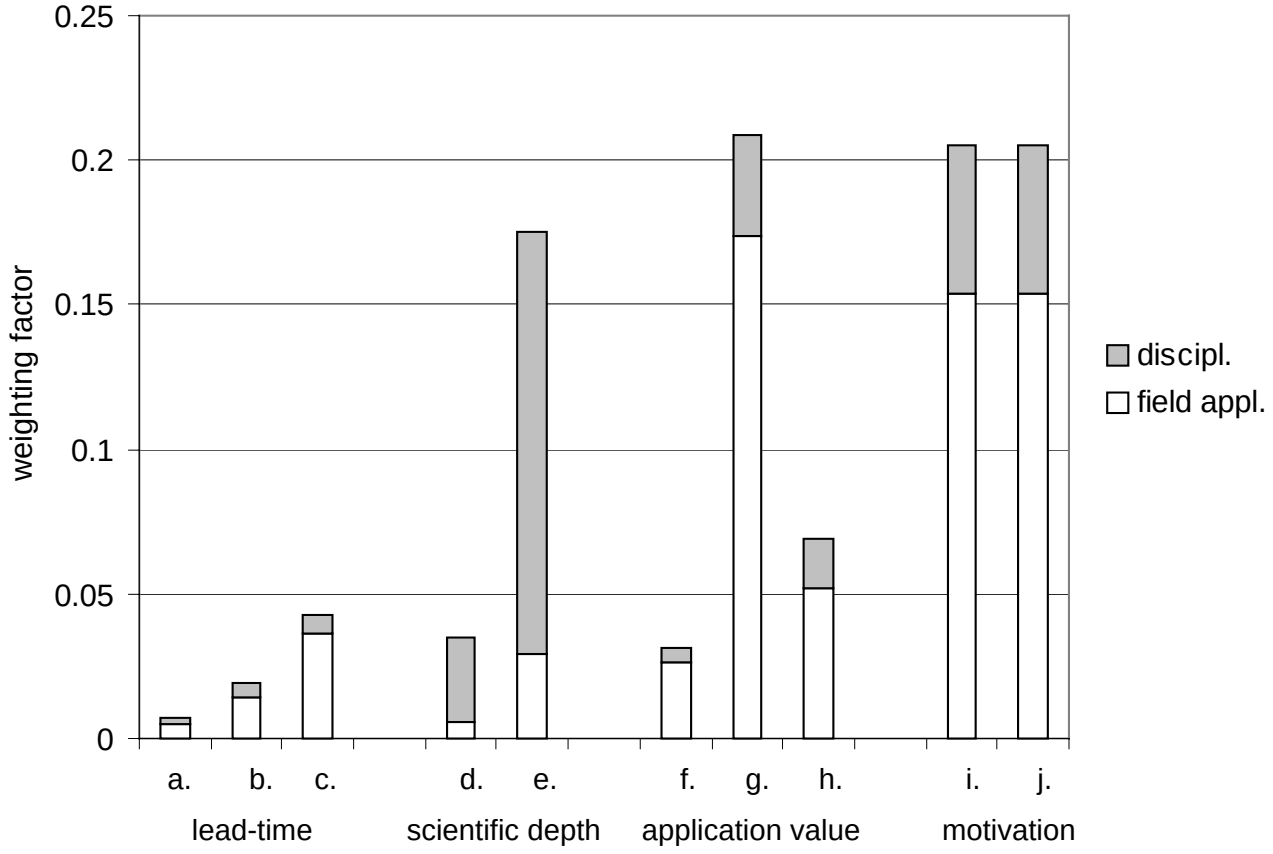


Figure 5a. Importances of the influences; second decision group

Notes: a. = efficient utilisation resources; b. = joint directions; c. = inventiveness; d. = professional growth by utilisation resources; e. = professional growth by interactions; f. = internal problem orientation; g. = external problem orientation; h. = integration internal competences; i. = satisfying interpersonal relations; j. = motivation task execution; discipl. = structure based on disciplines; field appl. = structure based on fields of application.

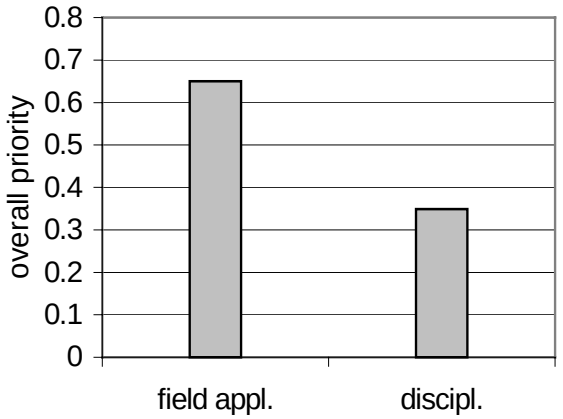


Figure 5b. Preferences for the alternatives; second decision group

Apart from a slight increase in the importance of motivation, no noteworthy changes in opinion have occurred since the group discussions during the application of the simple AHP structure. Nevertheless, with respect to this extended AHP structure, the similarities between the results from this decision group and the first decision group are striking. The importances of the first eight influences are affirmed by the judgements of the second decision group. When all influences on the efficiency and effectiveness are rearranged based on increasing importance, the order of the influences corresponding to both decision groups is exactly similar. Conversely, the second decision group assesses the importances of the two influences related to motivation as being much higher. The essential value of motivation was demonstrated by a lively example of an experience of one group member of this second decision group. However, this discrepancy did not result in significant differences of preference with regard to the organizational structure.

Furthermore, to a high degree, the two decision groups have analogue preferences with regard to the organizational structure, considering each of the ten influences separately. One exception is an efficient use of resources, the least important influence with respect to the decision regarding the organizational structure. This influence evoked divergent preferences. In contrast to the opinions within the first decision group, the second decision group expected that particularly a structure based on the fields of application would stimulate an efficient use of resources. The overall preference for a structure based on fields of application is reflected in the weighting factors of the alternatives. The weighting factors of a structure based on the fields of applications and a structure based on disciplines are respectively 0.65 and 0.35.

4.8 Conclusions and discussion

Many academic research centres are adapting their internal structure and processes to changing requirements of their external relations. Two organizational structures currently dominate the academic research units; a discipline-based and an interdisciplinary-based structure. This study has developed a decision method to support AO's choice for either an organizational structure based on disciplines or an interdisciplinary organizational structure based on the fields of application of research. Not only does this decision method take into account the motives for the choice for an organizational structure, it takes the desired but realistic strategic position of this academic research centre into consideration as well. Based on the importances of the external relations and their corresponding sources, a desired but realistic ratio of basic to applied research is determined. According to management involved, the computed ratio of basic to applied research is intuitively correct. A more objective evaluation of this complex matter will presumably be possible after several years. Within research orientations granted by the Faculty of Medical Sciences, AO desires to focus mainly on user-oriented applied research based on problems brought up by the university hospital. This ambiguous context is comparable to the context in which manifold reorganizations of academic research centres currently take place.

In choosing the most appropriate organizational structure for AO's type of research, effectiveness, efficiency and motivational values are considered. Influences on these factors have provided a sound foundation for the decision regarding the organizational structure. The influences on effectiveness and efficiency, noted in order of decreasing importance, are:

- Orientation towards external problems to enhance the application value of research projects;
- Professional growth by interactions to enhance the scientific depth of research projects;
- Integration of competences to enhance the application value of research projects;
- Inventiveness to enhance the lead-time of research projects;
- Professional growth by utilisation of resources to enhance the scientific depth of research projects;
- Orientation on internal problems to enhance the application value of research projects;
- Joint directions to enhance the lead-time of research projects;
- Efficient use of resources to enhance the lead-time of research projects.

The two comparable decision groups have independently chosen this specific order of influences. Furthermore, the importances of the following motivational aspects are not negligible for the decision regarding an organizational structure:

- Motivation with respect to the interpersonal relations;
- Motivation with respect to the task execution.

Apparently due to diverging emotional experiences, the two decision groups rated these aspects differently. A logical explanation is that these motivational aspects have a certain threshold value. Consequently, motivation can cause tremendous problems when the attained motivation is rated below this value.

Based on all influences, an overall preference for an organizational structure based on the fields of application is indicated by both decision groups. This overall preference is based on sub-preferences, related to each influence separately. The overall preference and even the sub-preferences between the two decision groups are highly similar. The differences with respect to the importances of the motivational aspects did not cause a significant difference between the overall preferences of the two decision groups. This is caused by the fact that the sub-preferences related to the motivational aspects are in tune with the overall preference for an organizational structure based on the fields of application.

All similarities between the judgements of the decision groups indicate that the extended backward AHP structure evoked a relatively objective foundation for the formerly contentious decision regarding the organizational structure. The influences with respect to scientific depth and application value of results induced opposite sub-preferences with regard to the organizational structure. These opposite preferences coincide with the prevailing disciplinary-based structures of university-oriented academic research units, in which scientific depth is emphasised, and the disposition of interdisciplinary-based structures of academic research units emphasising user-oriented research. In this respect, practice supports the realistic value of judgements based on the decision structure developed in this study.

Furthermore, AHP appeared to be a suitable approach for reaching a consensus in controversial decisions. Despite the existence of diverging interests, AHP evoked collective judgements based on a reasonable compromise or consensus. Therefore, seven of the eight decision-makers claimed to be willing to approve the consequences of this decision based on this foundation. The last decision-maker remained neutral.

In general, AHP is used either by application of a questionnaire or by group decision processes. The combination of both uses in this study proved to provide an additional value.

The decision-makers can systematically deliberate the specific comparisons before group decision processes take place. This creates an efficient dialogue in order to reach compromises. Efficiency is particularly important, since the amount of pairwise comparisons is relatively high due to redundant comparisons.

The collective judgements after group decision processes often deviated from the computed group means of the initial individual judgements. This deviation is an indicator for a high-quality collective decision (Sniezek and Henry, 1989). Furthermore, an improved quality appears from the relatively high consistencies in the collective judgements based on the combined uses of AHP.

A limitation is AHP's frequent inability to indicate those judgements that need to be revised. Expert choice gives a recommended revision regardless of whether the recommended value fits within the 9-points scale of AHP. An additional approach is recommended. The study of Genest and Zang (1996) can be a first instigator for a surveyable approach. Nevertheless, on the whole, AHP has been a useful tool in dealing with the multiple factors on different qualitative domains.

References

1. Armstrong JA. An industry perspective on the changing university. In: DS. Zinberg (ed.). *The Changing University*. London; Kluwer Academic Press: 17-23 (1991).
2. Barbarosoglu G, Pinhas D. Capital rationing in the public sector using the analytic hierarchy process. *Engineering Economist* 40(4): 315-341 (1995).
3. Bell G. Just say no to Uncle Sam. *Upside* 7(7): 70-75 (1992).
4. Bloedon RV, Stokes DR. Making university/industry collaborative research succeed. *Research Technology Management* 37(2): 44-48 (1994).
5. Bryson N. A goal programming method for generating priority vectors. *Journal of the Operational Research Society* 46: 641-648 (1995).
6. Bryson N, Mobolurin A. An approach to using the analytic hierarchy process for solving multiple criteria decision making problems. *European Journal of Operational Research* 76: 440-454 (1994).

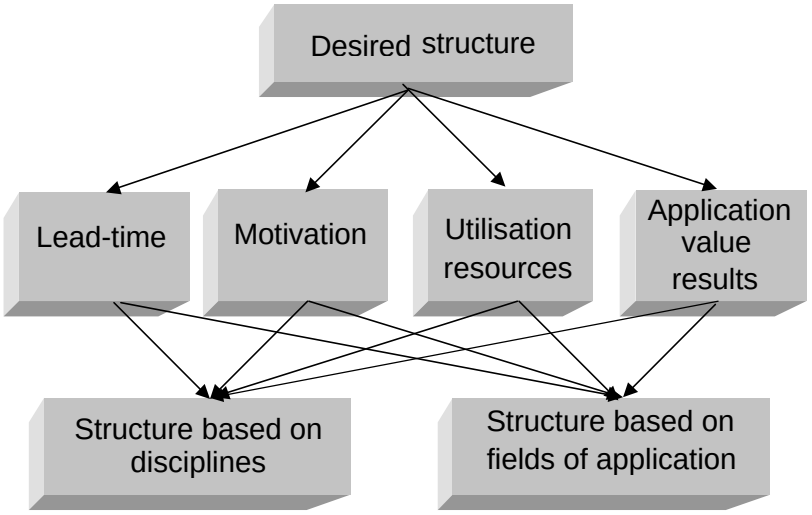
7. Bryson N, Mobolurin A. An action learning evaluation procedure for multiple criteria decision making problems. *European Journal of Operational Research* 96: 379-386 (1997).
8. Burnham JB. Evaluating industry/university research linkages. *Research Technology Management* 40(1): 52-55 (1997).
9. Carlsson C, Walden P. AHP in Political Group Decisions: A Study in the Art of Possibilities. *Interfaces* 25: 14-29 (1995).
10. Dasgupta P, David P. Towards a new economics of science. *Research Policy* 23: 487-521 (1994).
11. Davies RM. Industry-university collaborations: a necessity for the future. *Journal of Dentistry* 24(1-2): 3-5 (1996).
12. Davis L, Williams G. Evaluating and selecting simulation software using the analytic hierarchy process. *Integrated Manufacturing Systems* 5(1): 23-32 (1994).
13. Despotis DK. Fractional minmax goal programming: a unified approach to priority estimation and preference analysis in MCDM. *Journal of the Operational Research Society* 47(8): 989-999 (1996).
14. Dodd FJ, Donegan HA. Prioritization Techniques Using Interhierarchy Mappings. *Journal of the Operational Research Society* 46: 492-498 (1995).
15. Forsyth DR. *Group dynamics*, Pacific Grove CA; Brooks/Cole, 2nd edition (1990).
16. Geisler E. Universities, basic science, and technology transfer. *Journal of Technology Transfer:* 5-7 (1993)
17. Geisler E. When whales are cast ashore: The conversion to relevancy of American universities and basic science. *IEEE Transactions on Engineering Management* 42(1): 3-8 (1995).
18. Genest C, Zhang S-S. A graphical analysis of ratio-scaled paired comparison data. *Management Science* 42(3): 335-349 (1996).
19. Groenewegen P. Scientists, audiences and resources. The development of Dutch toxicological research. University of Amsterdam, Drukkerij van Denderen B.V. Groningen (1988).
20. Haselhoff F. *Ondernemingsstrategie een dilemma: de moderne ondernemingsstrategie in het spanningsveld van doelmatigheid, overleving en zingeving*, University of Amsterdam, Alphen aan de Rijn; Samson (1977).

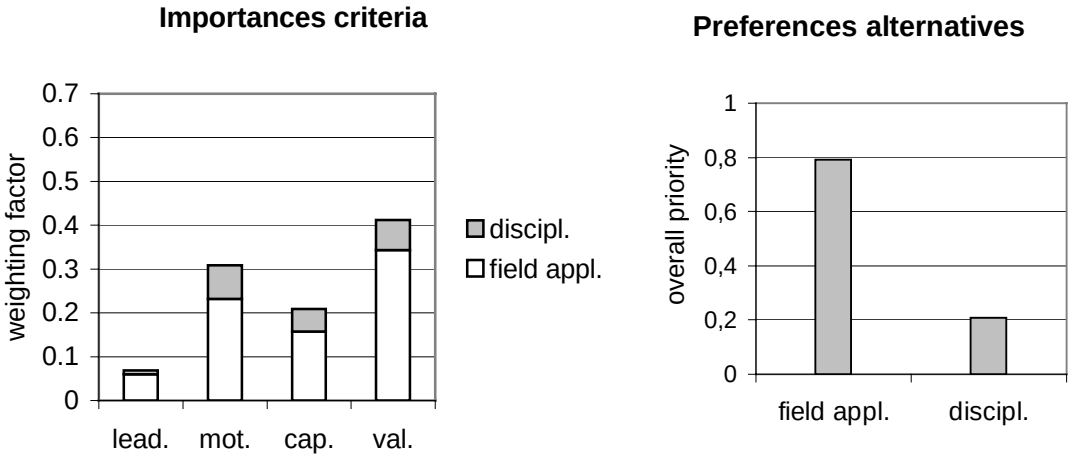
21. Hauser D, Tadikamalla P. The Analytic Hierarchy Process in an uncertain environment: a simulation approach. *European Journal of Operational Research* 91: 27-37 (1996).
22. Honert RC van den, Lootsma FA. Group preference aggregation in the multiplicative AHP; the model of the group decision process and Pareto optimality. *European Journal of Operational Research* 96: 363-370 (1996).
23. Howell WC, Dipboye RL. *Essentials of industrial and organizational psychology*. Pacific Grove, California; Brooks/Cole Publishing Company, third edition, 48 (1986).
24. Karbhari VM. The analytic hierarchy process: a viable decision tool for composite materials? *International Journal for Technology Management* 9(1): 77-93 (1994).
25. Keller RT. Predictors of the performance of project groups in R&D organizations. *Academy of Management Journal* 29(4): 715-726 (1986).
26. Lai S-K. A preference-based interpretation of AHP. *Omega, International Journal of Management Science* 23(4): 453-462 (1995).
27. Lee YS. Technology transfer" and the research university: a search or the boundaries of university-industry collaboration. *Research Policy* 25(6): 843-863 (1996).
28. Lee H, Kwak W, Han I. Developing a business performance evaluation system: an analytical hierarchical model. *Engineering Economist* 40(4): 343-357 (1995).
29. Libertore MJ, Monahan TF, Stout DE. A framework for integrating capital budgetting analysis with strategy. *The Engineering Economist* 38(1): 31-43 (1992).
30. MacKay DB, Bowen WM, Zinnes JL. A Thurstonian view of the analytic hierarchy process. *European Journal of Operational Research* 89: 427-444 (1996).
31. Madu CN. On the total productivity management of a maintenance float system through AHP applications. *International Journal of Production Economics* 34: 201-207 (1994).
32. Monsuur H. An intrinsic consistency threshold for reciprocal matrices. *European Journal of Operational Research* 96: 387-391 (1996).
33. Mulder K, Vergragt P. Weaving the superfibre network, or how the Akzo company developed its aramid fibre. Paper for 4S-EASST conference, Amsterdam (1989).
34. Ossadnik W. AHP-based synergy allocation to the partners in a merger. *European Journal of Operational Research* 88(1): 42-49 (1996).
35. Partovi FY. Determining what to benchmark: an analytic hierarchy process approach, *International Journal of Operations & Production Management* 14(6): 25-39 (1994).
36. Partovi FY, Hopton WE. The analytic hierarchy process as applied to two types of inventory problems. *Production and Inventory Management Journal* 26(1): 13-19 (1994).

37. Ramanathan R, Ganesh LS. Group preference aggregation methods employed in AHP: An evaluation and an intrinsic process for deriving members' weightages. *European Journal of Operational Research* 79(2): 249-265 (1994).
38. Ramanathan R, Ganesh LS. Using AHP for resource allocation problems, *European Journal of Operational Research* 80: 410-417 (1995).
39. Rahm D. Factors promoting and inhibiting technology transfer from university to firms. Paper presented at the AAAS Conference on University-Industry Cooperation: Results of Empirical Research 16-21 (1995).
40. Reid G. Improving university-industry relations. *SRA Journal* 26(1): 23-28 (1994).
41. Rhea J. Korea, Motorola research approaches aired at NAS. *Research Technology Management* 40(4): 7-8 (1997).
42. Rosenbloom ES. A probabilistic interpretation of the final rankings in AHP. *European Journal of Operational Research* 96: 371-378 (1996).
43. Rossum, W van, Omta SWF. Complications and pitfalls in R&D collaboration. In: *Corporate Social Capital and Liability*. Leenders RTh, Gabbay SM (eds.), Boston; Kluwer Academic Publishers (1999).
44. Saaty TL. Group decision making and the AHP. In*: The Analytic Hierarchy Process; Applications and Studies.* Golden BL, Wasil EA, Harker PT (eds.), Berlin, etc.; Springer-Verlag (1989).
45. Saaty TL. Homogeneteity and clustering in AHP ensures the validity of the scale. *European Journal of Operational Research* 72: 589-601 (1994).
46. Schoner B, Wedley WC, Choo EU. A unified approach to AHP with linking pins. *European Journal of Operational Research* 64: 384-392 (1993).
47. Sniezek JA, Henry RA. Accuracy and Confidence in Group Judgement. *Organizational Behavior and Human Decision Processes* 43: 1-28 (1989).
48. Shane SA. Why do some societies invent more than others? *Journal of Business Venturing:* 29-46 (1992).
49. Tang JCS, Nam IS. Sector priority and technology choice in the Korean machinery industry. *International Journal of Technology Management* 8(3-5): 333-341 (1993).
50. Thamhain HJ, Wilemon DL. Building High Performing Engineering Project Teams. *IEEE Transactions on Engineering Management* 34(3): 130-137 (1987).

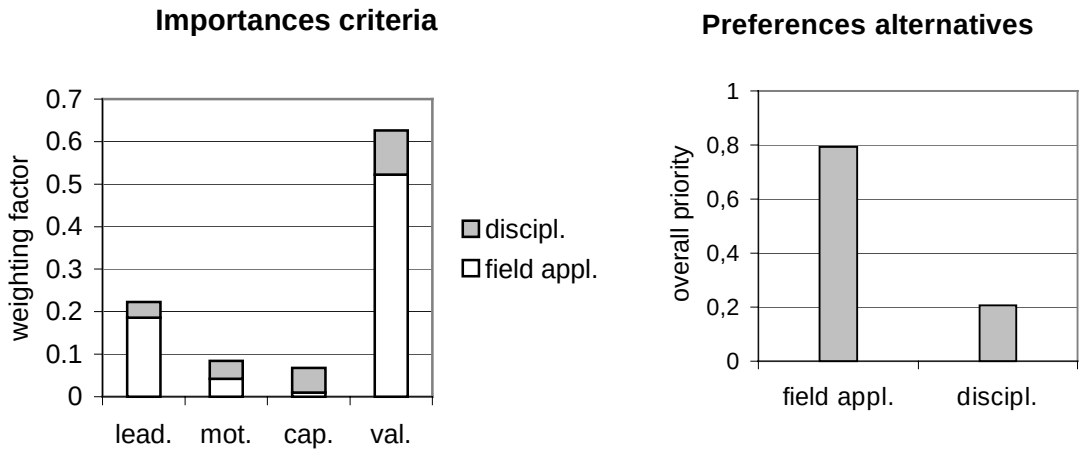
51. Tijssen RJW, Korevaar JC. Unravelling the cognitive and interorganisational structure of public/private R&D networks: A case study of catalysis research in the Netherlands, *Research Policy* 25: 1277-1293 (1997).
52. Whitley R. *The intellectual and social organization of the sciences*. Oxford; Clarendon press (1984).
53. Zeldenrust S. *Ambiguity, choice and control in research*. University of Amsterdam. Sneldruk, Enschede (1989).

Appendix 4.1. AHP structure and results of the pilot session





Decision group 1: Overall inconsistency ratio = 0.08 Required revisions = 2



Decision group 2: Overall inconsistency ratio = 0.04 Required revisions = 0